CHAPTER 4. DRILLING

4-1. Introduction.

a. Factors in selecting a drilling method include rock type, site conditions, scale of operations, hole diameter, hole depth, and labor and equipment costs. Factors in predicting drilling rates include machine capability and operations, type of bit, flushing, and rock type.

b. The basic purpose of drill holes in construction is for emplacement of explosives. The use of these same holes and cuttings removed from them in modifying and updating the knowledge of the project's subsurface conditions, however, should not be overlooked. The sources of some of the data in this chapter are references 5 and 9.

4-2. Principles of Drilling.

a. The common drill systems in use today are rotary, percussive, and rotary-percussive systems. Each is distinguished by its method of attack on the rock. A fourth system, jet-piercing, is used in the mining industry but has not yet become a standard method in civil excavation and will not be discussed further.

b. Drill bits may be classified by the shape of the cutting surface as conical, hemispherical, pyramidal, and prismatic. Applied forces transmitted to the rock through the bit are concentrated in the area of contact. The stresses at the contact and underneath break the rock. Experiments simulating the cutting actions of percussive and rotary drill bits indicate that rock fails in three distinct modes: crushing, chipping, and spalling (Fig. 4-1). Crushing and chipping are essentially static processes whereas spalling is caused by stress waves.[2] Stresses under a chisel bit are essentially compressional.[10] Crushing apparently results from failure of rock in a state of triaxial compression; chipping is due to fractures propagating from the vicinity of the crushed zone. Because of their significant effects on compressive strength of rock in general, the quartz content[11] and the porosity[12] (Figs. 4-2 and 4-3) are useful parameters for estimating drillability.

c. Analysis of the mechanics of drilling systems reveals limitations of each and indicates the most promising system for a specific type of rock. For example, a rock with a high compressive strength, regardless of its abrasiveness, is likely to respond well to the crushing-chipping action of a percussive bit. On the other hand, a relatively weakly bonded rock may not respond much better to percussive action, but will give good performance for a wear-resistant rotary drag bit (para 4-3c). A rule of thumb for choosing drilling methods in different

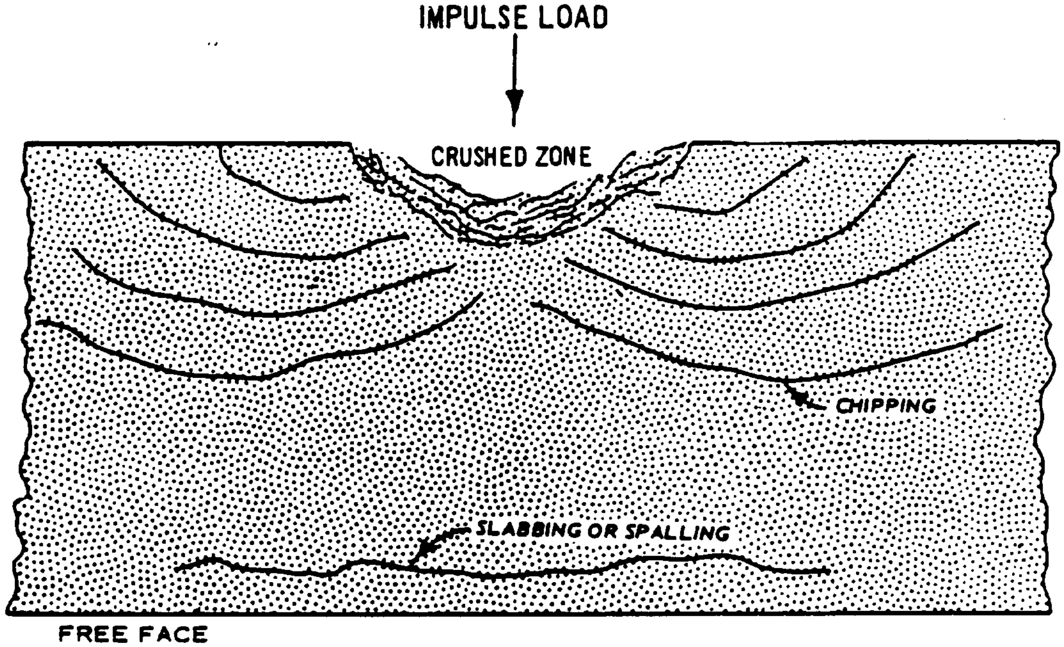


Fig. 4-1. Types of failure induced by a drill bit[2]

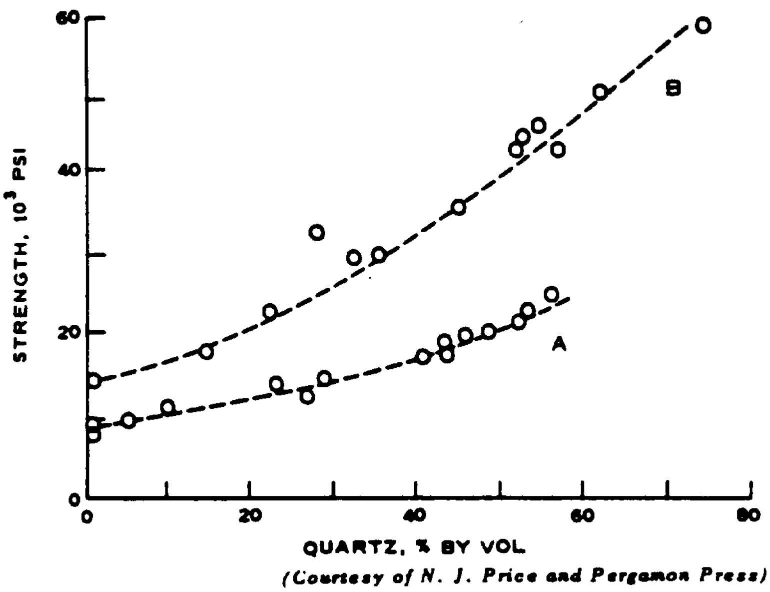


Fig. 4-2. Relation between quartz content and uniaxial strength of sedimentary rock. Curve A refers to rock with clay mineral matrices whose strengths have been corrected to eliminate the effects of compaction. Curve B represents rock types with carbonate matrices[11]

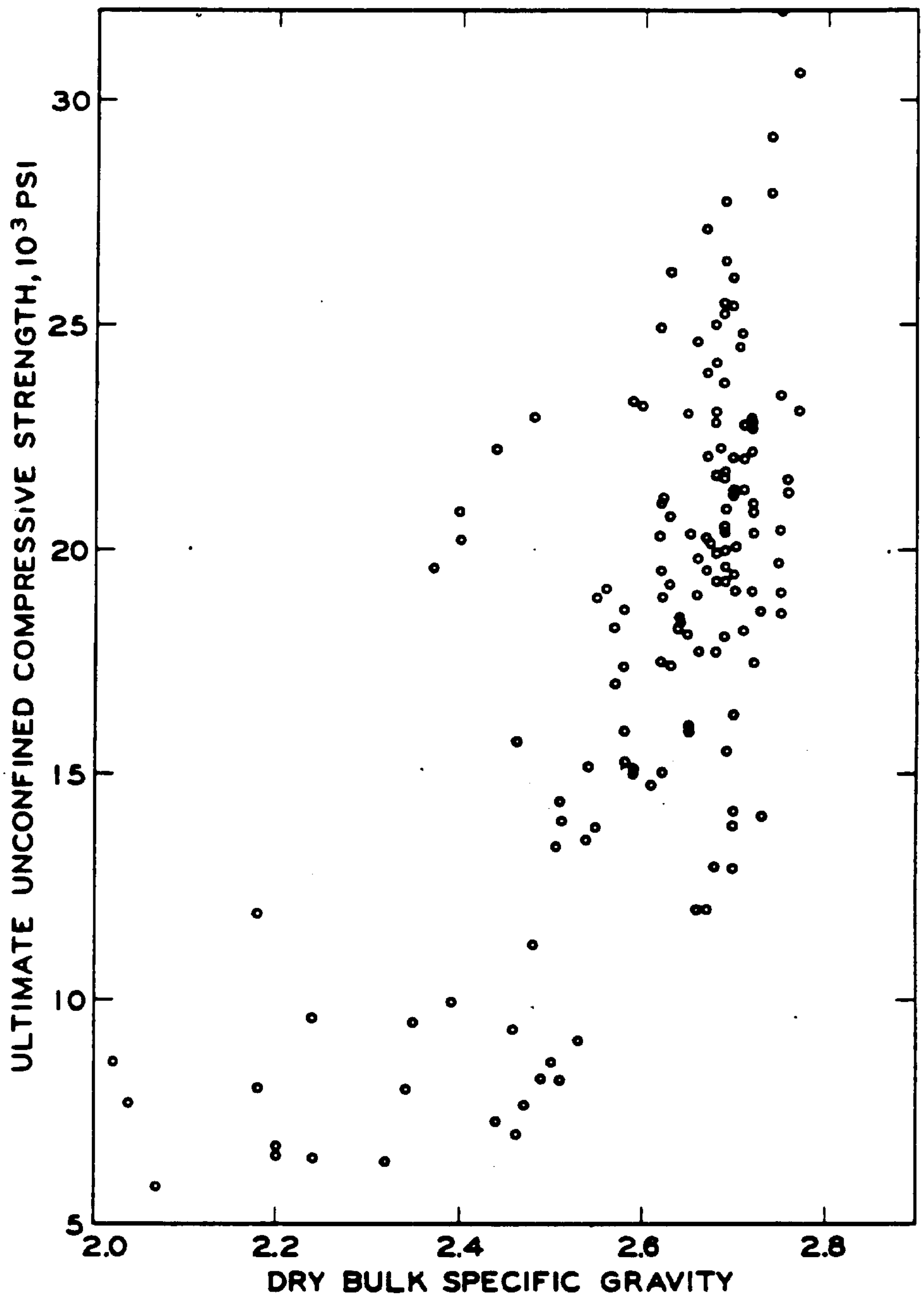


Fig. 4-3. Relation of compressive strength and bulk specific gravity for basalt[12]

rocks is shown in Table 4-1. A tendency for manufacturers to improve their machines and bits may allow each system to drill slightly more resistant rock than shown.

Table 4-1. Recommended Drilling Systems for Rock of Different Strengths[5]

System	Resistance of Rock to Penetration			
	Soft	Medium	Hard	Very Hard
Rotary-drag bit	X	X		
Rotary-roller bit	X	X	X	
Rotary-diamond bit	X	X	X	X
Percussive	X	X	X	X
Rotary-percussive	X	X	X	

4-3. Rotary Drills. The rotary drill (Fig. 4-4) imparts two basic actions through the bit into the rock: axial thrust and torque. Each machine has an optimum axial thrust interrelated with the available torque for a maximum penetration rate in a specific rock. Operating below the optimum thrust results in a decrease in penetration rate and may impart a polishing or grinding action. Operating above the optimum thrust requires high torque and tends to stall the machine. Rotary drills have higher torque than either percussive or rotary-percussive drills and require high sustained thrust. Rotary drills can be distinguished on the basis of the bit type. These are roller bits, diamond bits, and drag bits.

a. Roller Bits. Roller bits penetrate the rock mainly by crushing and chipping. They have conical cutters usually of sintered tungsten carbide that revolve around axles attached to the bit body. When the load is applied, the cutters roll on the bottom of the hole as the drill stem is rotated. Fig. 4-5 illustrates rock bits used for soft, medium, hard, and very hard formations. Roller bits are readily available in sizes ranging from 3 to 26 in. in diameter.

b. Diamond Bits. Diamond bits include those which cut full holes (plug bits) and those which take a core. In drilling with diamond bits, the hole is advanced by abrasive scratching and plowing action. The bit is generally cylindrical in shape with diamonds set in the contact area (Fig. 4-6). Arrangement and size of diamonds and location of water-flushing channel are determined by the rock to be drilled.

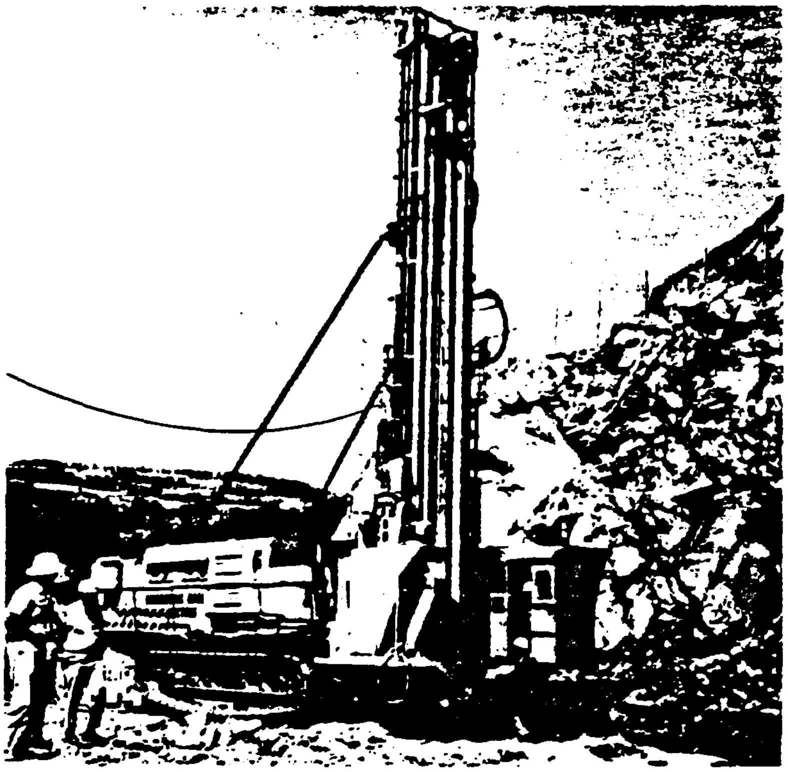


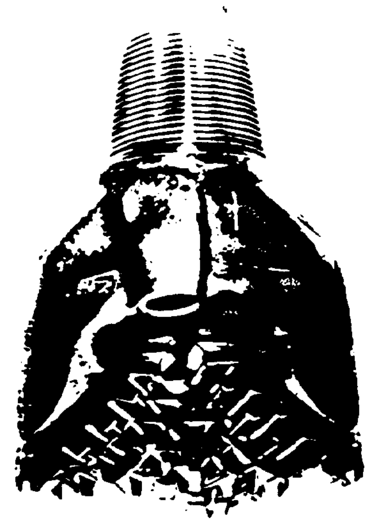
Fig. 4-4. Track-mounted rotary drill (9-in. bit)

Diamond bits require greater rotation speed but less bit pressure than roller bits. Blasthole drilling with diamond bits is limited in excavation work by the high bit cost, and most blastholes smaller than 3 in. (minimum size of roller bits) are drilled with percussive bits. Small-diameter diamond bits have been used extensively in the mining industry for blastholes, and therefore their possible use in civil projects should not be overlooked.

c. Drag Bits. Drag bits are designed with two or more blades as shown in Fig. 4-7. These blades are faced with sintered tungsten carbide inserts or have tungsten carbide interspersed throughout a matrix. Drag bits range in size from 1 to 26 in. and are used primarily in relatively soft rocks such as clay-shales.

d. Power Augers. Power augers are used in soft formations to speed up the removal of cuttings. The bit consists of a flat blade that continues up the shaft as a spiral. Cuttings move away from the bottom of the hole along this spiral. A wide range of hole diameters is

SOFT ROCK BIT - FOR CLAY, SHALE, SALT, GYPSUM, CHALK, ANHYDRITE, AND MEDIUM LIME ROCK.



MEDIUM ROCK BIT - FOR LIMESTONE, DOLOMITE, HARD SHALE, AND ANHYDRITE.

HARD ROCK BIT - FOR CHERT, QUARTZITE, DOLOMITE, AND SILICEOUS CARBONATE ROCK.

VERY HARD ROCK BIT - FOR CHERT, QUARTZITE, GRANITE, AND BASALT.

Fig. 4-5. Roller bits used in quarrying rock of different hardness[9]

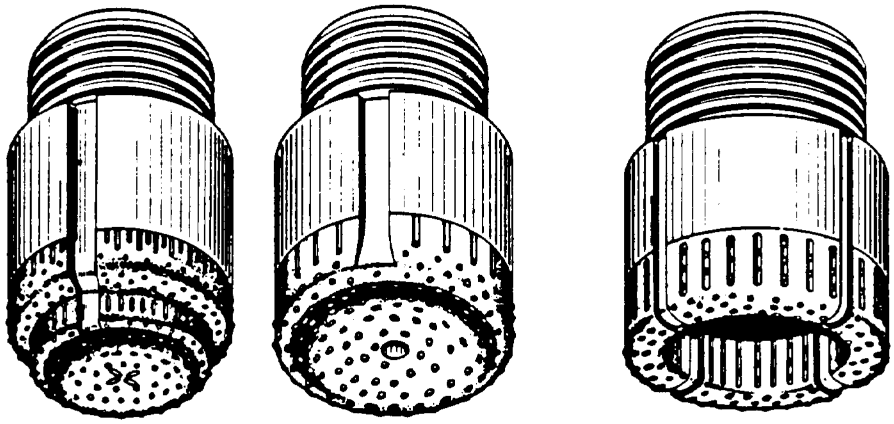


Fig. 4-6. Small-diameter diamond bits (3 in. or smaller)[9]

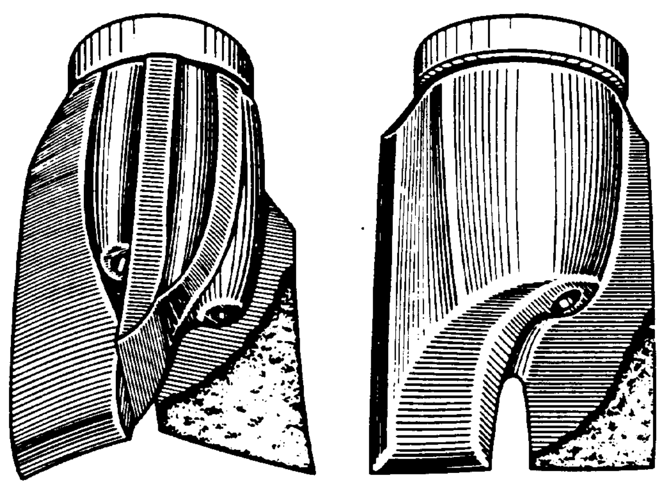


Fig. 4-7. Drag bits. Bits of this general type are available in sizes from 1- through 26-in. diameters and are used to drill soft formations[9]

available but hole depths do not usually exceed 100 ft. Although some power augers can theoretically be utilized in the same rocks as those drilled with drag bits, their principal use has been in very soft rocks or in soil.

4-4. Percussive Drills.

a. Percussive drills penetrate rock through the action of an impulsive blow through a chisel or wedge-shaped bit. Repeated application of large force of short duration crushes or fractures rock when the blow energy is of adequate magnitude. Torque, rotational speed, and thrust requirements are significantly lower for percussive systems than they are for rotary or rotary-percussive systems. Penetration rates in percussive drilling are proportional to the rate at which energy is supplied by the reciprocating piston.

b. Percussive machines include churn drills, surface hammer drills, down-the-hole hammer drills, and vibratory drills. Surface hammer drills are those in which the hammer remains at the surface. Down-the-hole drills are those in which the hammer is near the bit within the hole. They are generally used for larger holes. Vibratory drills, still in the development stage, use a mechanical, electrical, or fluid-driven transducer to deliver a high-frequency, periodic force to the bit.

c. Fig. 4-8 shows a small hammer drill. Several of the more common hammer bits and accompanying steel assemblies are shown in Figs. 4-9 and 4-10. Each bit holds replaceable tungsten carbide inserts. The bits are generally separate units detachable from drill steel. Hammer drills are capable of holes from 1-1/2 to 5 in. in diameter. Hammer drills are extensively used for blasthole drilling. The most commonly used types and their general characteristics are detailed below.

d. Jackhammers are hand-held, air- or gasoline-driven tools weighing from 37 to 57 lb. Air-driven models require between 60 and 80 cubic feet per minute (cfm) of air. Hole sizes range from 1-1/2 to 2 in., although larger drill bits are sometimes utilized in very soft rock. Jackhammers typically drill holes from 2 to 8 ft in depth and are seldom used to drill blastholes over 10 ft in depth. Stopers and drifters are larger hammer drills and were used originally in underground excavations.

e. Wagon drills (usually mounted on rubber-tired wagons) have in the past been one of the more useful tools for rock excavations (Fig. 4-11). Today, however, they are being replaced to a considerable

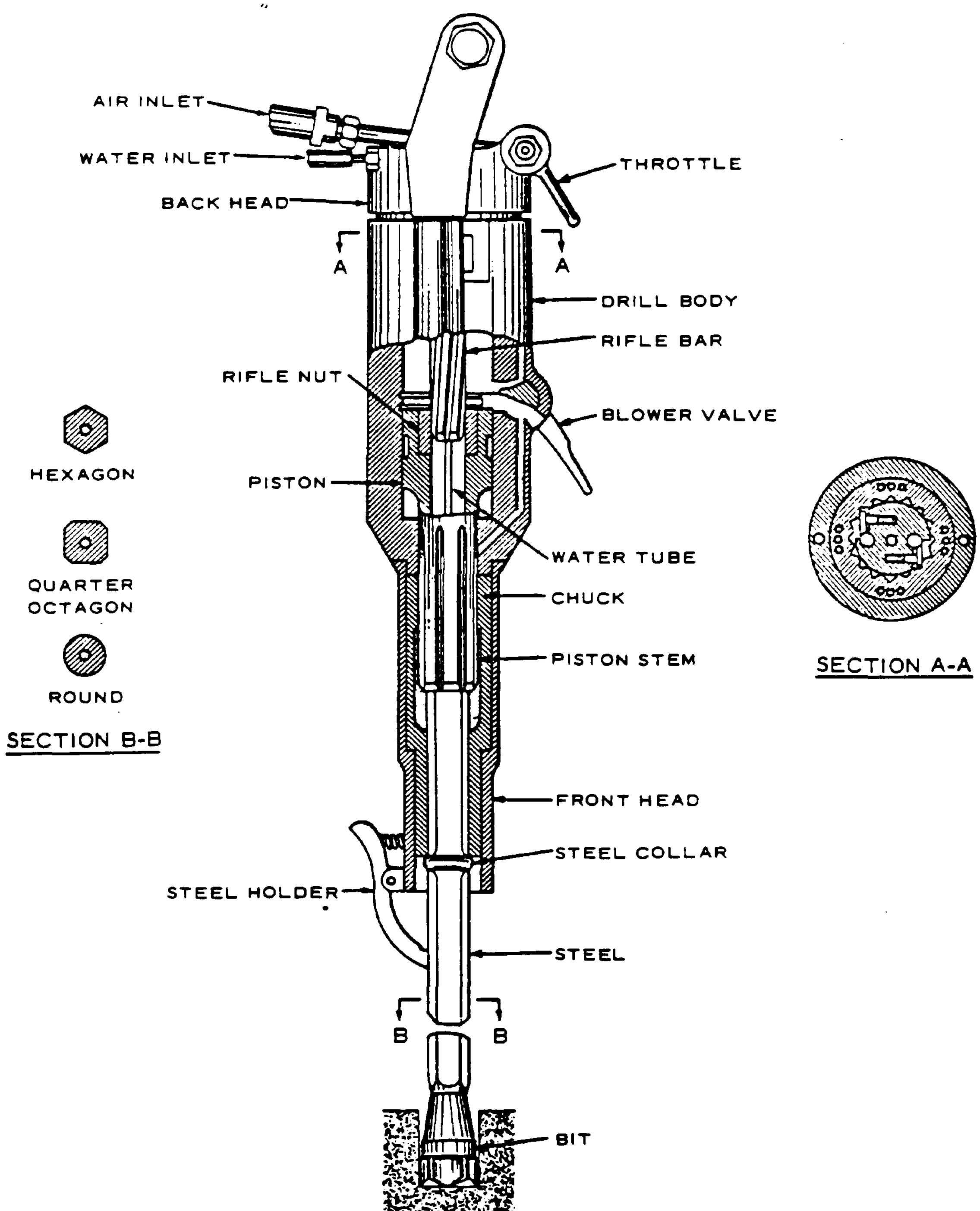


Fig. 4-8. Typical surface jackhammer drill design[9]

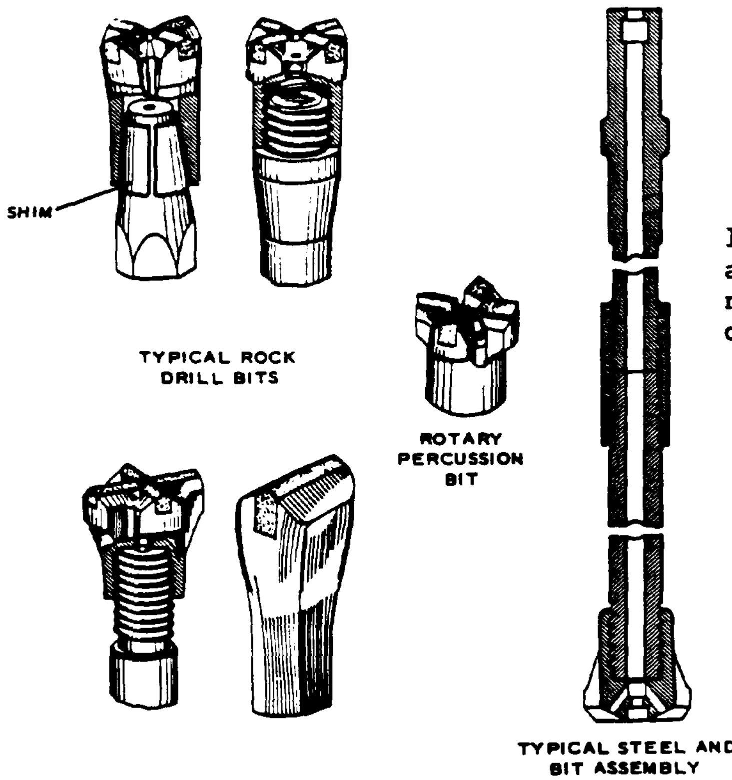


Fig. 4-9. Bits and steel assembly for surface hammer drills (figures show drive-on and threaded connections)[9]

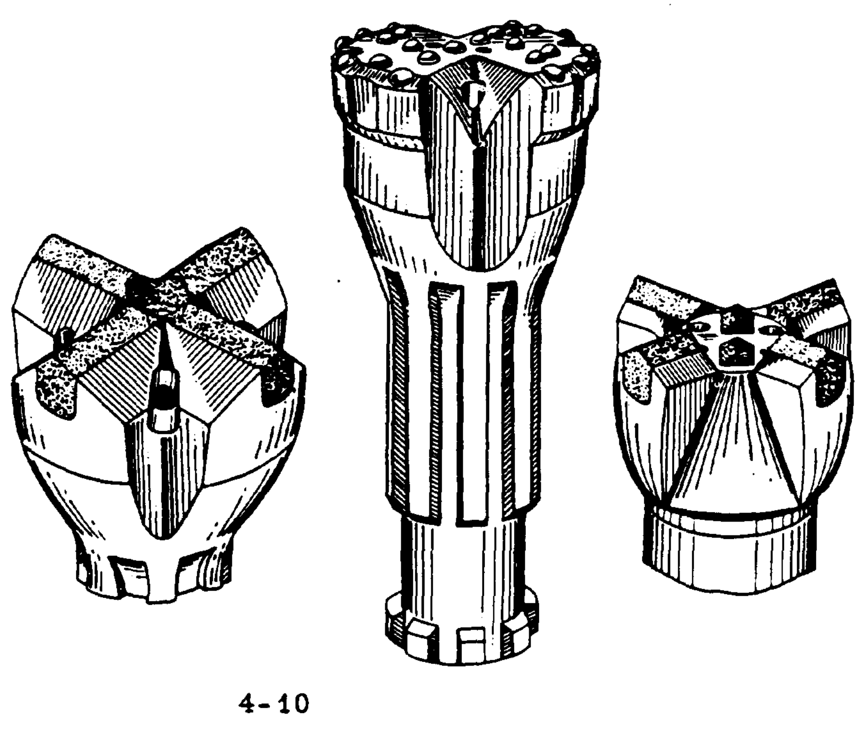


Fig. 4-10. Bits for down-the-hole hammer drill[9]

degree by heavier crawler drills. Wagon drills utilize 1-1/4-in. drilling steel, and bits range from 1-3/4 to 3 in. in diameter. They are most effective at depths of less than 20 ft. They require between 275 and 300 cfm of air and, thus, can conveniently be paired with a 600-cfm compressor.

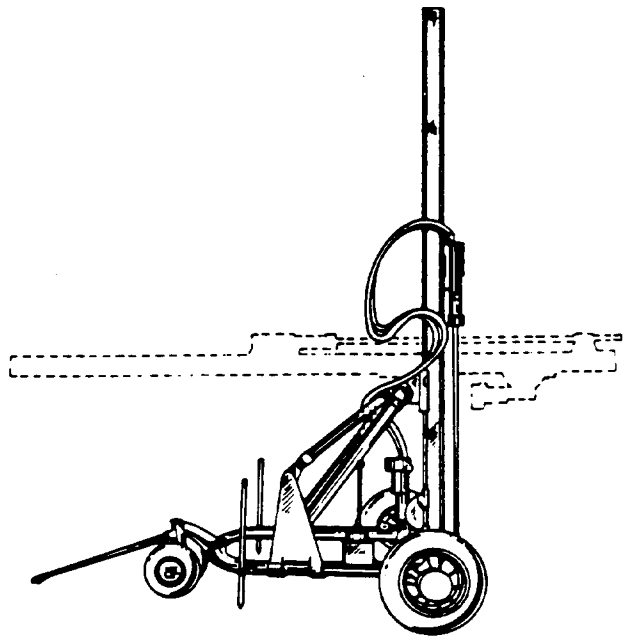


Fig. 4-11. Wagon drill[9]

f. A single wagon drill can drill from 200 to 400 ft of hole in a 9-hr shift. The rate may be less in very hard rock such as granite. Considered another way, a single wagon drill can make blastholes to produce between 500 and 1,500 cu yd of rock per shift, depending on the formation properties. At this average rate a contractor would need three wagon drills to stay ahead of a 2- or 2-1/2-yd shovel.

g. Crawler drills (Fig. 4-12) have become widely used tools in engineering excavation and have largely replaced the wagon drill. They are heavier units capable of drilling holes between 2-1/2 and 5 in. in diameter at any angle in all types of rock. These machines require about 50 percent more air, i.e. 150 cfm more than a wagon drill for a total of 450 cfm. Hole depths of 40 ft are routine and in some cases holes 100 ft in depth are put down with heavy models. Crawler drills can produce blastholes resulting in as much as two to three times more blasted rock per shift than wagon drills.

h. The churn drill penetrates by repeatedly raising and dropping a heavy chisel-shaped bit (Fig. 4-13) and tool string at the end of a cable. The cuttings suspended in mud in the hole are periodically removed with a bailer. Churn drills are seldom used today in construction.

4-5. Rotary-Percussive Drills.

a. Rotary-percussive drills impart three actions through the drill bit. These are (a) axial thrust, of lower magnitude than in rotary drilling, (b) torque of lower magnitude than in rotary drilling but higher than

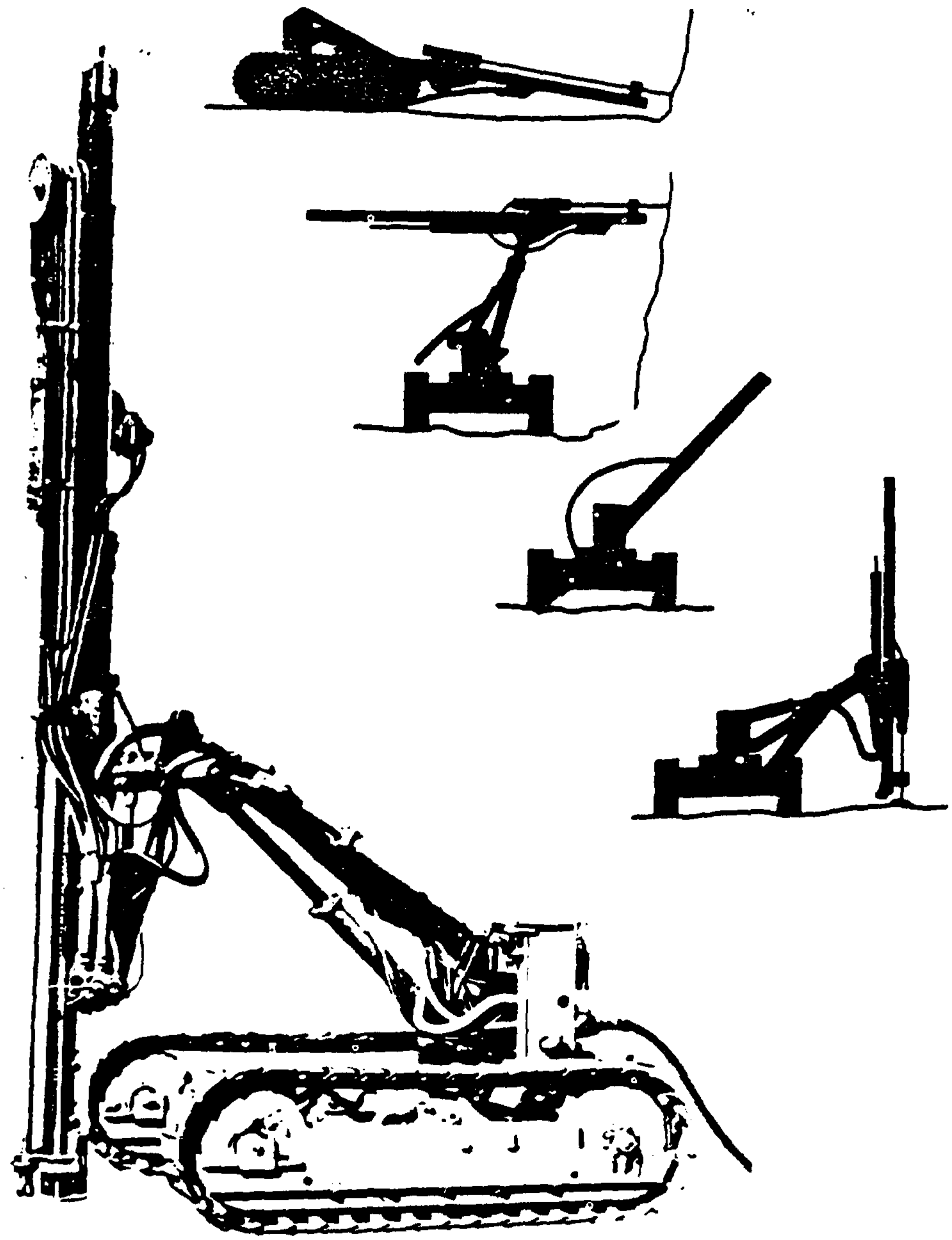


Fig. 4-12. Crawler drill capable of drilling holes from 1-3/4 to 3 in. in diameter. Insets show setup for various hole inclinations[9]

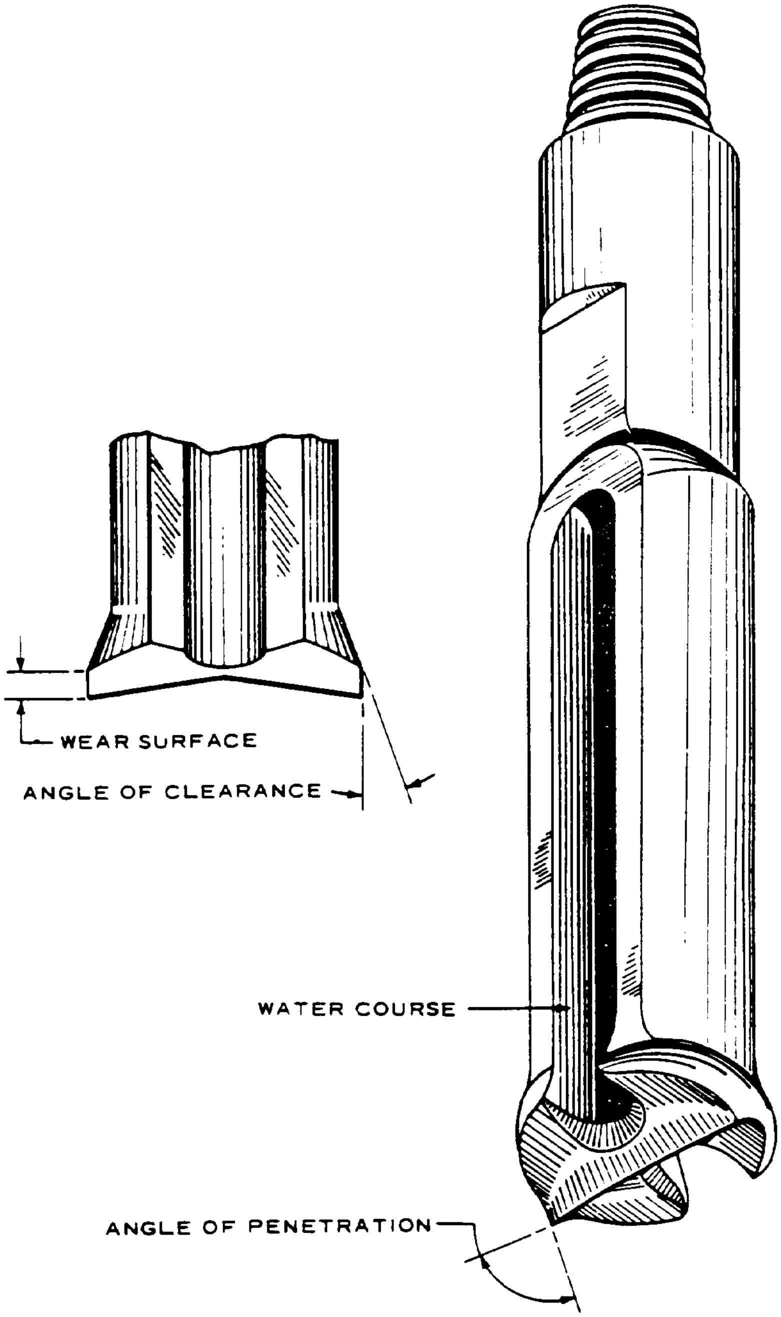
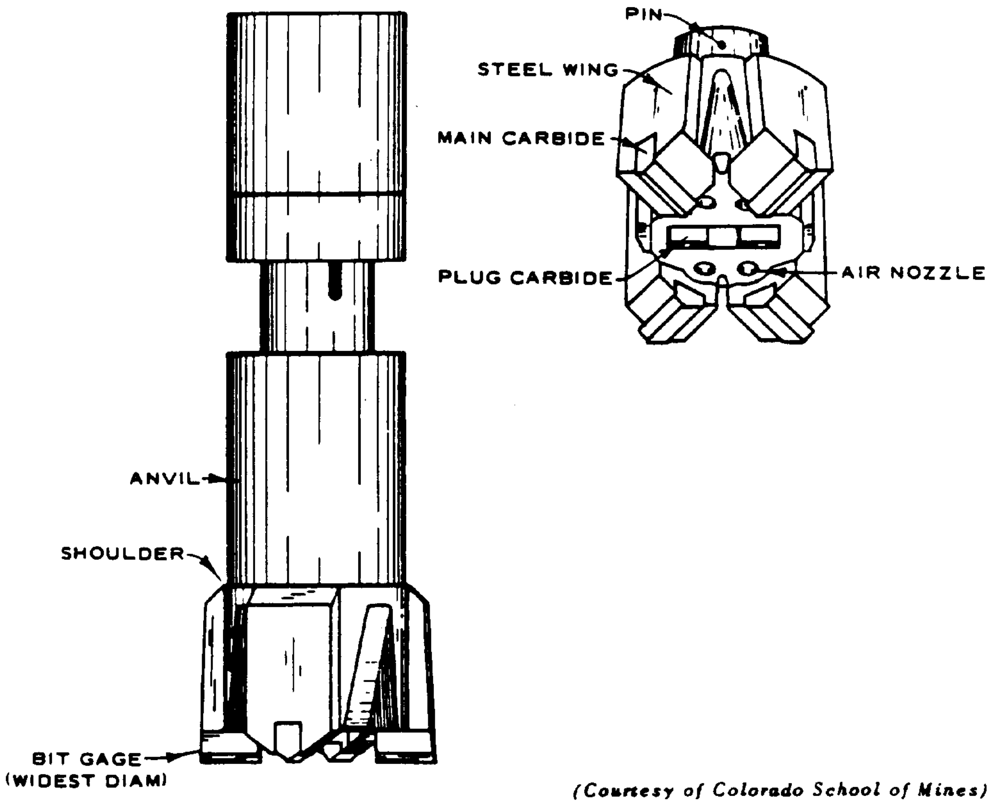


Fig. 4-13. Churn drill bit[9]

in percussive drilling, and (c) impact. Some drills have a rotation mechanism that is actuated by the impact mechanism; whereas others have a separate motor to achieve rotation. The mechanism of rock failure may be considered as a combination of the rotary and percussive mechanisms.

b. Drill bits such as those shown in Fig. 4-14 have been successfully used to drill deep blastholes from 4 to 9 in. in diameter. Conventional drill steel is used with down-the-hole drills, and since cuttings are removed up the annulus by air pressure, an air return velocity of around 50 fps is required. This velocity can be obtained with air supplies of around 15 cfm per in. of hole diameter in blastholes of moderate depth.



(Courtesy of Colorado School of Mines)

Fig. 4-14. Rotary-percussive drill bit (after Liljestrand[13])